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THE COMPRESSIVE STRENGTH OF MODERN EARTH MASONRY

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Abstract: Interest in earth building materials has grown in the UK in recent years. Though the use of traditional vernacular techniques, such as cob, adobe and rammed earth, have raised the profile of earthen architecture, wider impact on modern construction is likely to come from modern innovations such as extruded unfired masonry units. A large driver behind the move to earth masonry is the significant reduction in embodied energy when compared to fired bricks and concrete blockwork, and the passive environmental control provided by clay. This paper summarises results of extensive testing on commercial mass produced extruded unfired clay bricks. The focus of this paper is to investigate the properties affecting the compressive strength of these building products. Both theoretical models and test results demonstrate that the clay content plays a large role in defining the compressive strength of these materials. The reduction in strength with increases in moisture content are similar for different material sources and these strength reductions are unlikely to cause problems under normal operating conditions, even at high relative humidity and in shower rooms.

Keywords: *Earth, Masonry, Compressive, Strength, Moisture*

1 Introduction

With the increasing financial and environmental cost of energy production, low energy alternatives to conventional construction materials are becoming increasingly popular. One potential low-energy construction material is earth masonry. Earth masonry has been used in the construction of dwellings for thousands of years but has largely been replaced by high energy materials, particularly in developed countries. Commercially produced extruded unfired clay units (bricks or blocks) have about 14% of the embodied carbon of fired clay bricks and about 24% of the embodied carbon of lightweight blockwork (Morton, 2006). While there are advantages to using modern, high energy materials which generally have a higher strength and water resistance than unfired clay, there are many situations where these properties are not required and the cost and energy savings from

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using earth masonry instead of high energy materials in appropriate situations is attractive. In addition, unfired clay masonry has been shown to provide passive environmental control in buildings by buffering both humidity and temperature fluctuations which results in reduced heating, cooling and ventilation demands. (Morton, et. al., 2005; Minke 2006)

This paper presents results of investigations into the compressive strength of unfired clay masonry, particularly under changing environmental conditions. The bricks used for testing for the purposes of this paper were all commercially produced extruded bricks. Twelve different types (labelled A-I in this paper) were used but, because of the difficulty in producing consistent quality extruded bricks on a laboratory scale, each brick type was produced in a different brick plant as part of the normal production run. For reasons of commercial confidentially, the manufacturers of the different bricks are not identified for the majority of the tests, although some in-depth testing was performed on the Ecoterre brick produced by Ibstock Brick Ltd. All earth masonry units were intended to be “standard” brick size (215x102.5x65mm) if they were fired, but because they did not have additional shrinkage from firing, the average size was 223x106x67mm.

2 Unit and masonry strength

The European Standard for the compressive strength of masonry units is BS EN772-1:2000 (BSI, 2000a). This standard specifies a number of different conditioning procedures (air dry, oven dry, conditioning to 6% moisture content and conditioning by immersion). Immersing unstabilised unfired bricks is considered inappropriate as provided the materials are handled correctly and a building is detailed correctly, it is improbable that samples will ever achieve this condition. Three different curing conditions were used which were based on BS EN772-1:2000:

1. Oven dry – the samples were dried to constant mass at 105°C and then left to cool to ambient condition (20°C) before testing (according to BS EN772-1:2000).
2. Air-dry – Samples stored in a controlled environment of 20°C and 60% RH for a minimum of 14 days before testing (according to BS EN772-1:2000).
3. Applied moisture – Moisture is added to samples so they are tested at air-dry moisture content +2% (± 0.5%) moisture content. This was slightly modified from BS EN772-1:2000 as the moisture content in the standard (6% ±2%) was considered too broad a range for these moisture-sensitive materials.

The bricks were tested in a conventional concrete/ brick compression machine at a load rate of 0.05N/mm^2/sec until failure. This is the standard rate for masonry units with a peak compressive strength below 10N/mm^2, but for consistency this rate was used even for the units which had a strength slightly above 10N/mm^2. The strengths presented in this paper are the net strength of the material (i.e. total load across the cross section of the actual material – excluding any voids) and a correction was applied for unit size as per BS EN772-1:2000. The results of strength testing are shown in Figure 1.

Heath et al. (2009) demonstrated that an exponential form accurately represents the compressive strength of earth masonry units, and that the most important material property influencing compressive strength is the clay content (<0.002mm particles according to European convention). This is largely because of increased suction provided by smaller particles.

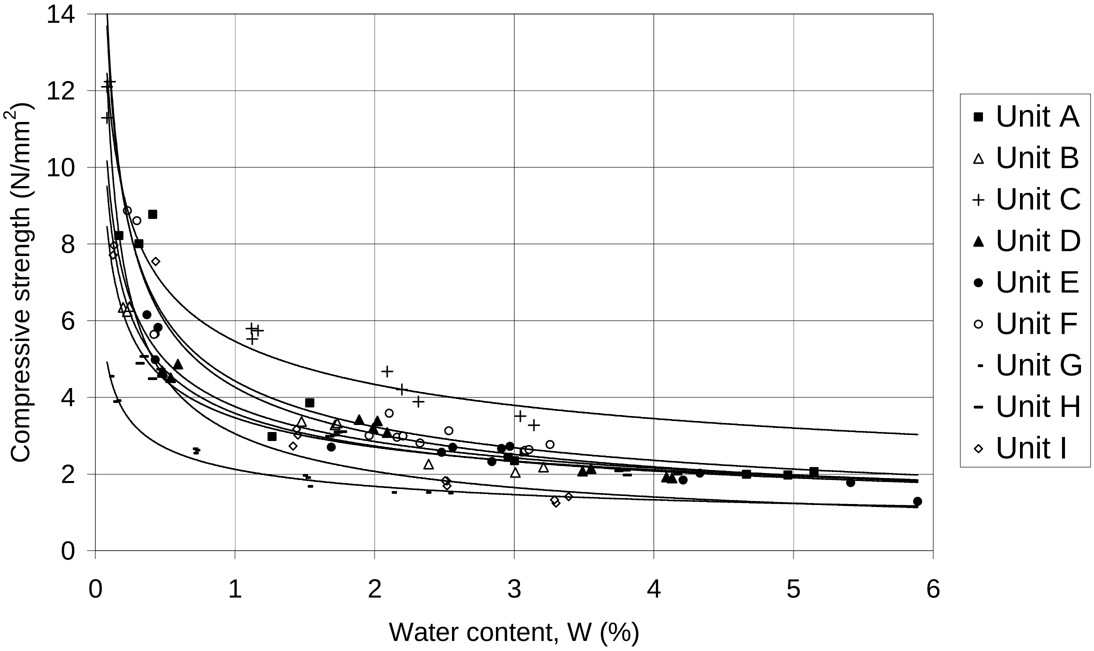

Figure 1: Unit compressive strength at different moisture contents

2.1 Effects of humidity on strength

Hansen and Hansen (2002) investigated the relationship between relative humidity and unfired clay brick moisture content and demonstrated that relative humidity levels of over 95% are required to achieve moisture contents over 5% by mass. This should be considered in light of measurements by Morton et al. (2005) which showed that the relative humidity in houses constructed with unfired clay masonry remains fairly constant at approximately 60% throughout the year.

The earth masonry units were tested according to BS EN 112571:2000 (BSI, 2000b). This involved measuring the moisture contents of samples of masonry units at different relative humidity levels. For the testing performed, the relative humidity was increased from 0% (oven dry state) to 100%, and down again to 0%. As the full range of humidity is unlikely to be achieved in practice, only values above 30% RH are presented and were used in fitting to a model. The model used in this case was that originally proposed by Hansen (1986) which although it has some shortcomings, is a simple model which represents behaviour across the range of interest. Although there is hysteresis in the wetting and drying during testing, this was ignored and a bit-fit to the Hansen equation is used for comparative purposes. The results of the testing are summarized in Figure 2 below. As shown, the earth masonry units have the ability to absorb significantly more moisture from the air than blockwork or fired masonry units, as mentioned by other researchers, e.g. Minke (2006).

The two models in Figures 1 and 2 can then be combined to determine the effect of relative humidity on unit strength, as shown in Figure 3. Because of the uncertainty in relative humidity measurement approaching 100%, only data up to 97.5% is presented.

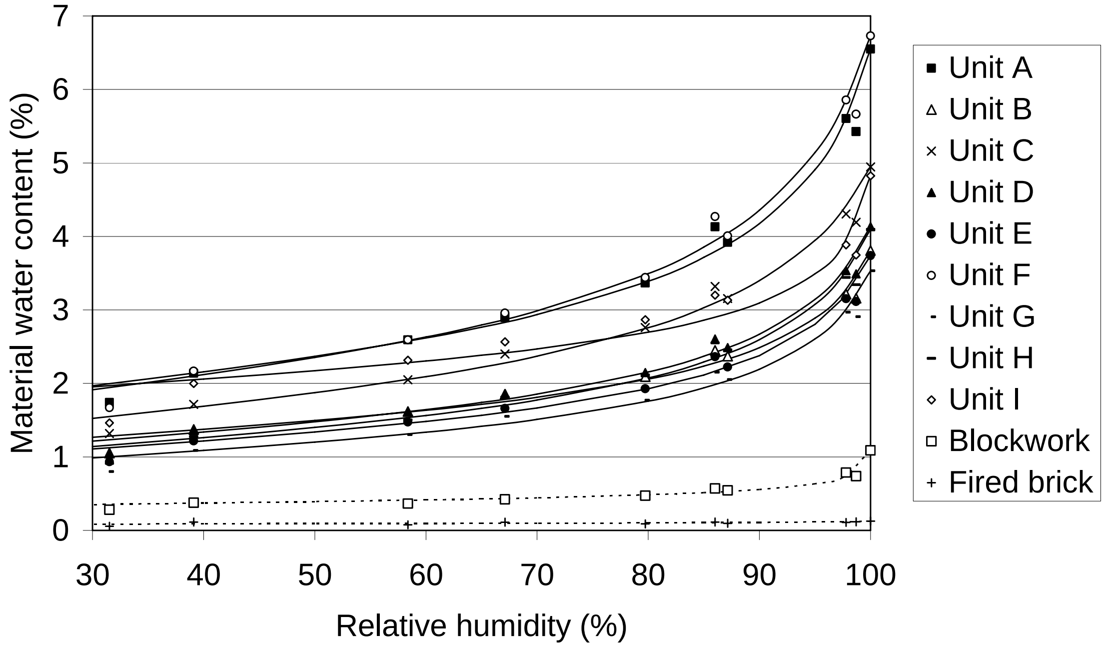

Figure 2: Effect of relative humidity on moisture content at 23°C

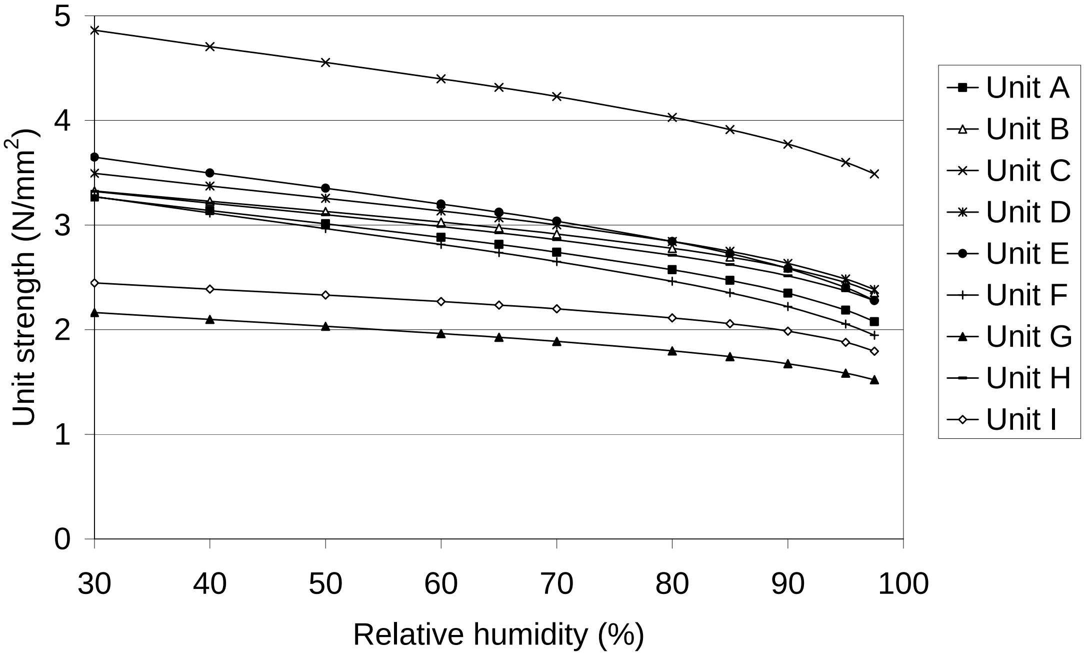

Figure 3: Effect of relative humidity on unit strength

2.2 Masonry testing

In addition to tests on the individual masonry units, testing was performed on the masonry with one of the units, the Ibstock Ecoterre (Unit B in the figures above). The Ecoterre was chosen as it has "average" properties when compared with other earth masonry units, and because it was developed specifically for use as an earth brick.

Testing was performed according to BSEN 1052-1:1999 and Figure 4 shows the test set-up and typical failure mode (vertical split through the wall thickness). The samples were stored in a controlled environment with temperature of 20°C (± 1°C) and 62.5% relative humidity (± 2.5%) prior to testing.

The failure stress (average of 6 wallettes) was 2.49N/mm^2 which, as expected, is slightly below the unit strength of approximately 3.0 N/mm^2 at the same relative humidity.

To put the strengths in context, the Building Regulations for England and Wales (ODPM, 2004) specify that for load-bearing aggregate concrete masonry units (typically 100mm thick), the declared unit compressive strength should be above 2.9N/mm^2 for air-dry conditions (below 65% relative humidity). As shown in Figure 3, the average strength of many of the sources tested exceeded this, but until further research is performed, using 100mm thick earth masonry units in loadbearing applications is not recommended.

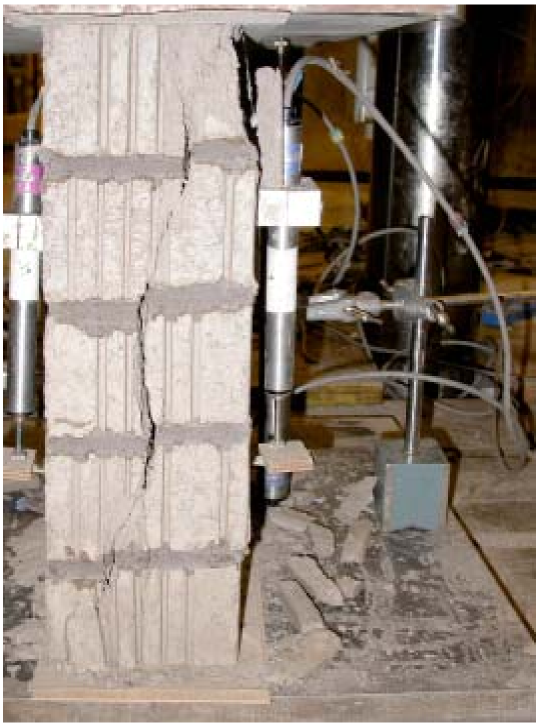

Figure 4: Typical mode of failure for compressive tests

3 Strength changes in earth masonry

3.1 Strength changes during service

People not familiar with earth masonry have indicated concerns that the strength will decrease to unacceptably low levels if used in rooms where humidity levels may be elevated. In order to assess this effect a 1mx1m unrendered test wall was constructed using the Ibstock Ecoterre and installed in a staff shower room at the University of Bath.

The shower room is approximately 15m^3 and is used by approximately 5 people every weekday morning. A small extractor fan is installed with a motion sensor so it will only run for 15 minutes after the last movement in the room. Amongst other tests, the moisture content was measured at different depths in the wall using 8mm diameter temperature / relative humidity sensors. As the test wall was small compared with the room (it represented approximately 5% of the available surface area), it was anticipated that the wall would not significantly affect the moisture conditions in the room, and this was confirmed by monitoring both with and without the test wall installed. This would minimise humidity buffering and provide a “worst case” scenario for both strength and moisture movement. Figure 5 shows the test wall in the unrendered state used for testing. While the figure shows measurement of dimensional change, this aspect is beyond the scope of this paper.

Figure 5: Test wall being measured for dimensional changes

The humidity was measured in the room, at 15mm into the wall and at 50mm into the wall (100mm thick). Using Figure 3, the strength can be inferred from the measured humidity but this required the humidity to be normalised for temperature which was manually done. The measured humidity in the room (not normalised for temperature) and the humidity 15mm into the wall are shown in Figure 6, along with the calculated average strength from the complete moisture profile through the wall.

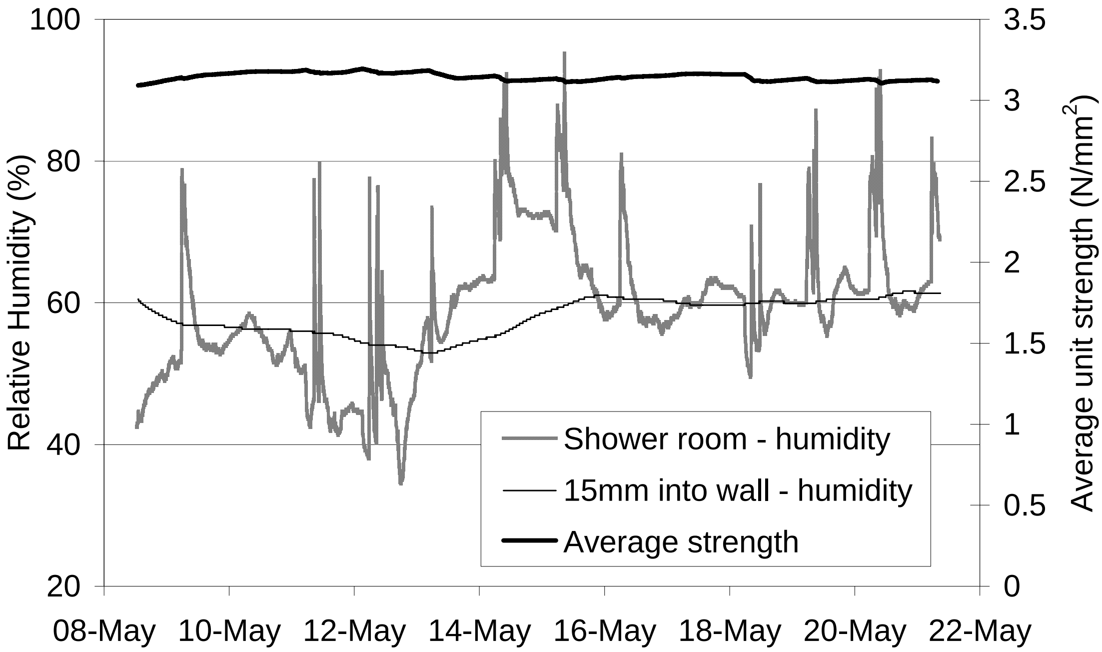

Figure 6: Humidity in room, 15mm into wall, and calculated strength in shower room

As shown in Figure 6, the changes in humidity in the shower room resulted in insignificant changes in strength in the earth masonry (maximum of 3% change), dispelling the myth that the strength will be significantly reduced if used under these conditions. The changes in humidity in the wall relate to moisture being stored at times of high room humidity and released when the room humidity decreases.

Providing appropriate detailing is used (Minke, 2006 and Morton, 2009) and use is appropriate, any other wetting during operation should be minimised and also result in insignificant decrease in strength. Appropriate detailing includes a small plinth of water resistant concrete blockwork or fired clay units at every floor level and ensuring drainage is away from earth masonry walls in rooms with water supply. Appropriate use includes not using these materials in areas prone to flood risk. The performance under extreme wetting events such as firefighting is difficult to quantify, and the performance of other forms of construction (such as timber framed and lightweight concrete blockwork) under firefighting is also questionable.

3.2 Strength changes during construction

Provided detailing of a building is appropriate, the most likely source of this wetting would be from the application of render to an unfired clay brick wall. Tests were performed, again with the Ibstock Ecoterre, to determine the effect of rendering on moisture movement and strength. As in the previous section, the dimensional change aspect is beyond the scope of this paper.

Although it is common to use earth renders in thin layers, for this study only two cases were investigated – a nominal 12mm render layer (dried to 11.4mm) and a nominal 6mm render layer (dried to 5.6mm) using an undercoat plaster produced in Germany by Claytec and supplied in the UK by Natural Building Technologies. In both cases they were applied as a single layer with a moisture content of 19.3%. The same methodology and unit (100mm thick Ibstock Ecoterre) as in the shower room study were used, with the exception that the study was performed in a controlled environment with a temperature of 20°C (± 1°C) and 62.5% relative humidity (± 2.5%). The effect of rendering on unit compressive strength is illustrated in Figure 7 below.

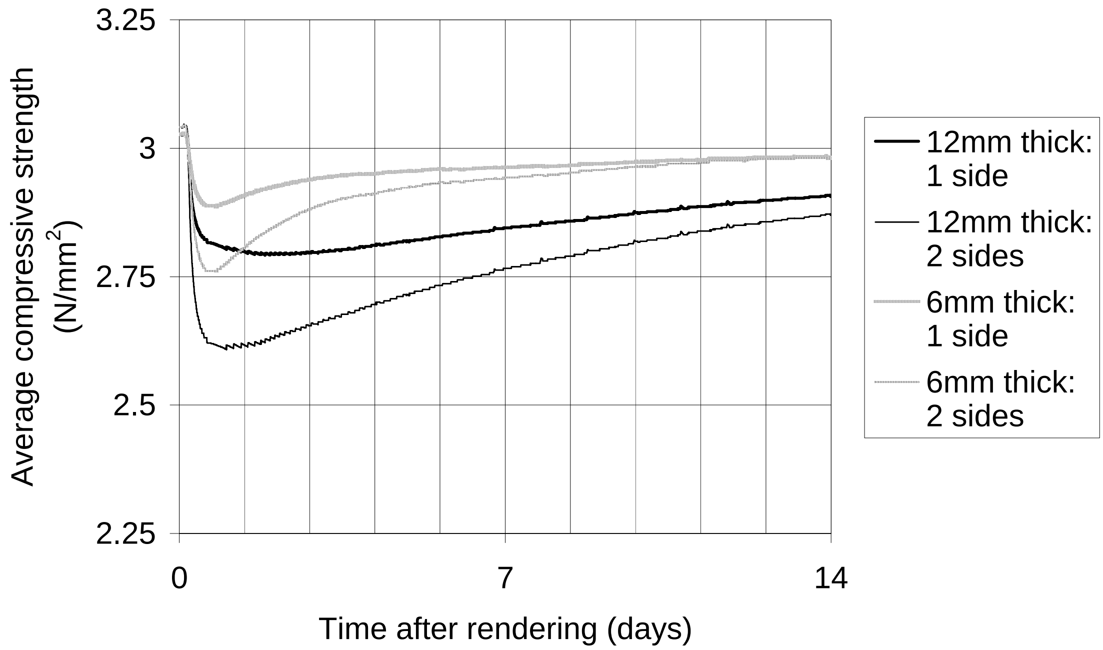

Figure 7: Effect of rendering on average unit compressive strength

As shown in Figure 7, the unit strength starts decreasing after rendering, reaching its minimum strength within 2 days and then increasing. The greatest strength reduction was

0.44N/mm^2 (15% of the peak strength). As expected, a thicker render results in a larger strength reduction, as does rendering on both sides of a wall. Any stresses induced by the differential expansion caused by rendering on one side are beyond the scope of this paper.

4 Conclusions

This paper has presented results into an in-depth study into the compressive strength of modern earth masonry. Based on the information presented, it can be concluded that although the material are moisture sensitive, changes in relative humidity (even those experienced in a shower room) will not produce significant reductions in compressive strength. Under normal operating conditions the compressive strength of modern earth masonry can even be above the minimum specified for 100mm thick load-bearing concrete masonry units in domestic house construction in the UK, but until further research is performed, they are not recommended as a direct replacement for concrete blockwork.

Providing detailing is appropriate and protection is provided during construction, the minimum strength is likely to come during construction, specifically after rendering. If a 12mm render is applied as a single layer to both sides of a 100mm thick wall there can be 15% strength reduction, but in experiments performed as part of this study, the minimum strength was achieved within two days after rendering and then increased again. Placing a render as a 12mm thick single layer is not normal practice in earth masonry construction and is therefore unlikely to occur.

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